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ASTROPHYSICS

July 1, 2000

The Surroundings of Disturbed, Active Galaxies

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Received April 1999

Abstract. The brightest apparent magnitude examples of ultra luminous infrared galaxies (ULIRG's) are studied here in X-ray, optical, infrared and radio wavelengths. It is found that they have associated material reaching out to apparent diameters of the order of a degree on the sky.

Gas, dust, X-ray material and quasars appear to be ejected from the active nuclei with all objects nearer than their redshift distances.

Key words: Galaxies: active - Galaxies:individual (Mark 273, Mark 231, Arp 220) (*Galaxies:*) quasars: general - Radio sources: 21 cm radiation - Galaxies: X-rays

1. Introduction

The neighborhoods of the most active ULIRG's, Mark273, Mark231, Arp 220 and NGC6240 plus the radio galaxy 3C31/NGC383 are examined for associated objects.

2. Markarian 273

A strong jet emerges S from the disturbed central regions of this ULIRG. Fig.1 shows that both Mark 273 ($z = .038$) and the compact object Mark 273x ($z = .458$) are strong X-ray sources. The deep optical image in Fig. 2 illustrates the conclusion by Xia et al. (1999) that "Mark 273x is at the tip of the plume" reaching NE from Mark 273.

Fig.3 addresses the question of whether there is any X-ray connection between Mark 273 and the AGN to the NE. The outer isophotes do not appear as rounded as one would expect from accidental adjacency of unrelated, symmetrical sources. (See for example the contouring of two adjacent, unrelated images in Arp 1998a, Fig. 1-12). In addition the bright central regions of Mark 273 are conspicuously extended toward Mark 273x.

In fact what we see is a compact optical object of $R = 19.6$ mag. and redshift $z = .458$ connected back to a disturbed Seyfert 2 of $V = 14.9$ mag. by both optical and X-ray emitting material. Mark 273x is the same kind of

quasar-like object which was physically associated with somewhat brighter Seyfert galaxies at a 7.5 sigma level (Radecke 1997; Arp 1997). Also there is a recent precedent for a quasar of $z = 2.15$ at the tip of an X-ray/optical filament emerging along the minor axis of the active galaxy NGC3628 (Flesch and Arp 1999).

The luminosity of the quasar-like Mark 273x as derived by Xia et al. (1998) when they believed it to be connected to Mark 273 was $M_R = -17.6$ mag. But we will argue later that Mark 273 itself is quasar-like in that it has an intrinsic redshift and should be moved of the order of 5 magnitudes (in modulus) closer.

Smoothing and contouring the lower resolution, PSPC X-ray measures produces Fig. 4. It is seen that the outer contours of Mark 273x verify the elongation to the NE, along a line back toward the central galaxy. Regardless of whether this x-ray connection is due to a jet or to some merger related activity it does establish the fact that the two objects are at the same distance. There is, however a clear X-ray jet visible in the PSPC measures. It comes out of Mark 273 to the SE and is delineated even in the 3,4 and 5 sigma contours (also more weakly in the opposite direction).

There is no reason not to have jets coming out of active galaxies in different directions. In fact there is considerable evidence for lines of X-ray sources emerging from Seyfert and other active galaxies (Arp 1996;1997). Why those apparent ejections take place in roughly orthogonal directions, as here in Mark 273, there seems to be no ready explanation, but it does seem to be an empirical result. As we shall see there is evidence for X-ray material and objects coming out further along these same principal directions.

As for the relation of Mark 273x to Mark 273, the ejection of higher redshift quasars and quasar-like objects has been argued for more than 30 years (see Arp 1983; 1998a). But the interesting additional information given by these *disturbed*, active galaxies is that when quasars do not come out along relatively unimpeded along the minor axis, that they then interact with the material of the ejecting galaxy and disrupt it, giving rise to disturbed morphologies, entrainments and fragmentation (Arp 1999a).

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3. Markarian 273 Radio Features

It is most interesting to consider the information in other wavelengths, not only to confirm the features we have already seen but also to try to understand the physical processes involved in the ejections, if that is the mechanism for producing these associations.

In Fig. 5 we see the map of the Mark 273 region in continuum radio wavelengths. The most prominent feature is a broad ejection coming out NW and SE, agreeing closely with the direction of the X-ray jet. (Close to the nucleus, agreement between X-ray and radio jets is characteristic of very active radio galaxies like Virgo A and Centaurus A). In the counter jet direction the radio extension is longer but weaker. Overall, there seems to be confirmation that both X-ray and radio emitting material are coming out of Mark 273 at position angles of about 130 and 310 degrees.

The next most conspicuous feature in Fig. 5 is the very strong radio source about 5.5 arcmin SW of Mark 273. This radio source is a close double (about 1.1 arcsec separation and p.a. about 20 deg when viewed on the VLA, high resolution mode, FIRST). Doubtless of companion radio and X-ray sources will be noted as we explore other active galaxy neighborhoods. But of considerable significance for the ejection hypothesis for Mark 273x is the fact that it is itself a strong radio source, and that it is *aligned, as exactly as can be measured*, across Mark 273 with the strong radio source to the SW.

Fainter radio extensions than contoured in the preceding Figure are shown here in Fig. 6. They extend both NW and SE generally along the direction of the radio and X-ray jets. (The arrow in Fig. 6 marks the X-ray jet pictured in Fig. 4). Surprisingly there are two low surface brightness radio filaments extending from Mark 273 and ending on two very strong X-ray sources (in Fig. 7 they are marked as Nos. 21N and 38 and are at 6.2 and 6.6 arcmin respectively from Mark 273). They are marked with x's in Fig. 6. One is a quasar of $z = .941$ and the other is a blue stellar object (BSO) with a similar apparent magnitude, of 18.1. The latter will almost certainly turn out to be a second quasar in a pair. In the deep red exposure of Fig. 2 there are twin, low surface brightness *optical* filaments coming out of the S end of Mark 273. (Seen better in deeper image in J. Hibbard's home page.) They appear to lead into the radio filaments which are observed in Fig. 6. In summary, it appears that in all the wavelengths that can be checked, radio, optical and X-ray, there is a connection of these two strong X-ray sources back to the center of Mark 273.

Because of the apparent quasar nature and consequent high redshift of these two strong X-ray sources it is customary to ask whether they could be accidentally projected background sources. We can answer this suggestion by noting that the strength of these X-ray sources: Mark 273x = 8.3 cts/ks, $z = .941$ quasar = 37.7 cts/ks and 18.1

BSO = 21.2 cts/ks indicates that they would have a chance of being background sources falling as close as they do to Mark 273 of $p = .003, .01$ and $.04$. Altogether getting just these three objects this close to an arbitrary active galaxy would only be about one chance in a million. Xia et al. (1999) note in passing that it is interesting that "... the X-ray companions of the three nearest ULIG's (Arp 220, Mrk 273 and Mrk 231) are all background sources...".

4. X-ray field around Mark 273

Since X-ray sources and quasars have been associated with Seyfert galaxies out to distances of nearly a degree it is of interest to see what the full PSPC field of ROSAT around mark 273 looks like.

The strong sources that we have been discussing are seen close to the center of Fig. 7. The two probable quasars are seen to be exceptionally strong X-ray sources at 21 and 38 cts/ks, much stronger even than Mark 273 and 273x which have 13 and 8 cts/ks. As we go off-axis the point spread of the images enlarges so only the brighter sources are registered. It is clear, however, that sources of all brightness are distributed in an elongated pattern, roughly NE to SW through Mark 273. This line is close to the direction of Mark 273x and the strong, double radio source pictured in Fig. 5 (p.a. ~ 40 deg.).

Of course the radio and X-ray ejections which lead toward the two strong X-ray sources (21N and 38) are in an almost orthogonal direction to this (p.a. ~ 140 deg.). They are suggested to be connected with the the strong X-ray sources 16 and 30 which lie further out in this direction. As Table 1 shows, both the 16 and 30 cts/ks X-ray sources are optically identified as blue stellar objects (BSO's) and therefore are most probably a quasar pair like so many of the X-ray sources paired across Seyfert galaxies.

Ejection in more than one direction from active galaxies is commonly observed (see Arp 1996; 1997a; Komossa and Schulz 1998). *The most important aspect of Fig. 7, however, is that numerous X-ray sources in this field are aligned preferentially across Mark 273, confirming that they are predominantly not background.*

TABLE 1
Bright X-ray sources in Mark 273 field

Cts	R.A. (2000)	Dec.	E	O-E	ID	Remarks
49	13 41 36.2	55 14 37	16.93	1.99	c.g.	
26	13 42 06.3	56 39 15	16.52	1.20	BSO	47" off pos
16	13 42 21.6	56 14 50	19.88	.73	BSO	
18	13 44 13.5	56 30 34	18.30	.34	BSO	
21S	13 44 57.3	55 28 22	18.9	.85	?	extend?
38	13 44 47.3	55 46 56	17.76	.77	QSO	$z = .941$
13	13 44 42.1	55 53 13	14.9*	.77*	S2	Mark 273
8	13 44 47.1	55 54 10	19.25	1.78	c.g.	Mark 273x
21N	13 45 12.0	55 47 59	18.1	.57	BSO	
29	13 45 33.4	55 24 06	19.26	.66	BSO	
8	13 46 06.7	56 04 29	19.08	.28	BSO	
30	13 46 38.9	55 27 09	19.44	.32	BSO	
48	13 46 59.1	56 07 04	18.21	1.49	BSO	

* B and B-V magnitudes

5. Infrared sources aligned with Mark 273

In order to investigate the Mark 273 surroundings in longer wavelengths the Simbad on-line catalog was consulted. It was noticed immediately that there was a conspicuous string of what turned out to be infrared sources coming generally SW from the ULIRG galaxy. Fig. 8 shows a plot of nearly the same sized area as pictured in the preceding PSPC X-ray map. *Only infrared point sources with 100 micron fluxes greater than .5 Jy have been plotted.* The sources are as listed in the IRAS faint source catalog of 173,044 sources. It is clear that there is a general line of deep infrared sources coming from the center of the Mark 273 region in roughly the same direction (p.a. = 235 deg.) as the Mark 273x/radio double and X-ray material (220 deg.).

6. Radio sources around Mark 273

Among the three closest radio sources to Mark 273 at 4.85 GHz (Becker et al. 1991), there is a 42 mJy extended source 18 arcmin NE and a 27 mJy source 35 arcmin SW. A little further in this direction (46 arcmin) there is a radio source of 31 mJy which appears to coincide with the strong X-ray source of 49 cts/ks mapped in Fig. 7. This same source is identified in Table 1 as a compact galaxy. These outer radio sources lie closely along the NE-SW direction of the inner radio sources Mark 273, 273x and dbl source SW (see Fig. 5).

Radio ejections from active galaxy nuclei are well accepted. X-ray ejections from Mark 273 have been shown here. Physical association of X-ray sources has been shown in the past - for example six Seyferts, including Mark 273, were shown to have a factor 8 higher X-ray source density around them (Turner et al. 1993). A sample of 24 of the brightest Seyferts were shown to have paired X-ray sources across them, the great majority of which must be quasars or quasar-like (Radecke 1997; Arp 1997). The alignment of radio sources and X-ray quasars from these conspicuously ejecting ULIRG's would sug-

gest, therefore, that material in various different forms is ejected.

We now see that for Mark 273 the infrared sources in Fig. 8 are distributed around a principal line of ejection. It raises the question of how they are related to the ejection process and the other ejected material.

7. Markarian 231

Fig. 9 shows that flanking Mark 231 there is a double radio source about 7.5 arcmin W and another double 2.2 arcmin to the E. (The latter has a faint companion to the NE making it actually a triple). Fig. 9b aligned directly below Fig. 9, and to the same scale, shows that radio material is being ejected toward the E from Mark 231 and that presumably the sources to the W represent counter ejection in the other direction. The X-ray source to the east (left) is optically identified with a BSO and extended in the NE direction *as are also its radio contours.*

It is important to note that there is a faint but definite X-ray jet extending to the N from Mark 231. This is the same direction as the radio extensions to the N and some small spots of radio emission as shown in Fig. 9b. Closely to the S of Mark 231 there is an extended radio source (Condon and Broderick 1998) and in the inner 60 milliarcsec there is a strong N-S triple source (Ulvestad et al. 1999; Taylor et al. 1999). All of this is evidence for ejection and outflow of material in this direction, a direction which only shifts by 5 deg. in p.a. from the innermost to the outermost aligned sources (over 3 deg. distant for the infrared sources that we shall see later).

As we have seen in other cases here there is evidence for ejection in more than one direction from an active galaxy. In the case of Mark 231 the strong double radio source 7.6 arcmin slightly S of W is an obvious counter ejection to the radio sources emerging from Mark 231 on the E. The W source is conspicuous in that it is a close double. (The sources on the E are also closely multiple).

The most striking object of all, however, is the *double X-ray source* which is aligned back through the double radio source to the nucleus of the galaxy. An obvious interpretation is that as the X-ray source travelled outward from Mark 231 it had its radio plasma stripped from it. This could occur in transit of a homogeneous medium surrounding Mark 231, in conjunction with a discrete event of generation of radio plasma. Or it could be simply an encounter with a discrete density enhancement in the medium.

It is apparent in Fig. 9 that at a slightly greater angle to the SW, there is another X-ray source with a radio source trailing at about the same distance behind it. In this and the previous case it is noticeable that the radio sources are slightly above the line from the X-ray source back to Mark 231. This suggests that the medium which stripped the plasma is rotating relatively slowly counterclockwise.

Proof of such a mechanism would illuminate several puzzles about ejection of matter from active galaxies. To this end we point to Fig. 9c which shows that the double X-ray source is identified with a double quasar. (The brighter X-ray source is catalogued as $z = 1.272$ and the optical image 52 arcsec E is appreciably bluer implying a highly probable QSO of redshift to be determined). The properties which support the relation of the double X-ray source to the double radio source are then: 1) The relation of the stronger components of the double to the weaker. 2) The similar orientation of the radio double, p.a. = 65 deg., and the X-ray double, p.a. = 75 deg. The separation of 52 arcsec of the images in the X-ray and optical compared to the 24 arcsec separation of the radio images would then imply a continuing separation of the X-ray images since the event of the stripping of the radio plasma.

Thanks to the detailed observations of Alan Stockton (astro-ph/9801056) we can support this picture with observations of the radio galaxy 3C212. Fig. 10 shows that the optical objects f and g have passed out beyond the radio material. The peculiar, identical shape of the radio contours and the optical material leaves no doubt that the radio plasma has been removed suddenly from the optical objects as they progressed away from the ejecting galaxy. It is also revealing to note that the redshift of the material in the galaxy is $z = 1.05$ whereas the optical object, f, has $z = .93$. (Ejection velocities relative to the active objects, and presumably their surrounding medium, have been shown to be of the order of .1c. (Arp 1998a)).

If this suggested mechanism of plasma stripping in fact operates, it furnishes us with a general explanation of why the radio emission and the X-ray/optical objects can be generally but not exactly in the same positions. In fact we will see later that in the famous radio galaxy, 3C31/NGC383, that strong radio filaments trail toward the position of some high redshift galaxies and an even higher redshift quasar. But the radio track is rotated somewhat from the X-ray/optical objects.

If the plasma generating events in quasars are intermittent it might help us understand why, among similar appearing quasars, some are radio sources and some are not. The higher percentage of quasars identified with X-ray sources than with radio sources could be explained by the fact that X-rays and optical synchrotron radiation would decay relatively quickly and therefore be much closer to the denser core of the quasar itself. Periodic gas ejection events could also supply multiple clouds to account for those quasars with multiple absorption line systems.

Markarian 231 turns out to be particularly well suited to test these suggestions because the lines of radio and X-ray ejection are so well marked. Proceeding from the milliarcsec interior they appear fairly constant in direction out to almost a degree on the sky. Perhaps this is due to the lack of rotational or precessional angular momentum imparted by these particular ULIRG's, as suggested by their irregular morphologies.

8. Surroundings of Mark 231 in the Infrared

In the infrared field of Fig. 11 the long arrow shows the direction and distance of the 136 cts/ks X-ray source, 3C277.1, plus the spread of the radio ejections around this direction. The short arrow shows the extent of the radio and X-ray ejection N from Mark 231. The IR source is in the direction of the radio and X-ray ejection at p.a. = 243 deg. (The probable identification of this source is Y Uma but there is a 1RXS, X-ray BSO within 23 arcmin.) There are also three sources aligned to the N at about p.a. = -10 deg., which is close to the inner radio and X-ray ejection to the N at about p.a. = -5 deg.

If these cold sources (they are perhaps even more prominent at 100 microns) are ejected from Mark 231 they confirm the result obtained in Fig. 8 for Mark 273. The large angular separation of around 3 degrees on the sky, however would imply that Mark 231 was much closer than the conventional redshift distance. Cold infrared sources would also pose again the question of whether they were proto quasars or by-products of the ejection.

9. The X-ray field around Mark 231

Fig. 12 shows the distribution of the brightest X-ray sources around Mark 231 (14.3 cts/ks). This is the same elongation of radio sources and X-ray sources as discussed in connection with Fig. 9. The strong, 136 cts/ks X-ray source which is 36 arcmin SW of Mark231 is optically identified with a relatively bright BSO at E = 16.5 mag. as shown in Table 2. There is a moderately strong X-ray source, 22.3 cts/ks at 50 arcmin to the NE of Mark 231 (not registered in Fig. 12) which is identified with a bright BSO of E = 17.4 mag. This is the most promising pair of AGN's to be identified with the major ejection event of which we see the traces in the interior. The 17.5 cts/ks X-ray source is the candidate double quasar shown in Fig.9.

TABLE 2

Bright X-ray sources in Mark 231 field									
Cts	R.A.	(2000)	Dec.	E	O-E	ID	Remarks		
136	12 52 26.2	56 34 20	16.47	1.17	BSO	3C277.1			
15.4	12 54 49.1	57 04 52	19.72	.47	BSO				
16.1	12 54 51.5	56 44 30	17.03	1.43	Bcg				
17.5	12 54 56.7	56 49 42	19.21	1.53	QSO	$z = 1.272$			
"	12 55 02.9	56 49 54	19.24	.65	BSO	see Fig. 11			
8.1	12 55 24.7	56 56 14	19.53	.23	BSO				
4.9	12 55 28.2	56 46 40	-	-	-	no candidate			
14.3	12 56 14.2	56 52 25	13.84*	.84*	S1	Mark 231 $z = .041$			
4.2	12 56 30.8	56 52 19	19.06	.44	BSO				
4.8	12 56 48.3	57 03 45	19.77	.63	BSO				
22.3	13 00 33.5	57 28 35	17.35	.62	BSO				
78	13 00 43.3	56 21 28	19		blue BSO	30"S of brt star			
117	13 00 52.1	56 41 05	16.27	.88	BSO	possibly one or			
"	13 00 54.5	56 41 11	19.03	1.12	BSO	both are QSO's			

* V and B-V

Optical identifications will be discussed after Arp 220.

10. Surroundings of Arp 220

This ULIRG displays a chaotic morphology with strong dust absorption. Fig. 14 shows that neutral hydrogen extends from the active galaxy down to companions situated about 2 arcmin to the SW (Hibbard, Vacca & Yun, 2000).

Fig. 15 shows that the brighter X-ray sources form a N-S string in the shape of a shallow "S". These X-ray sources seem to be ejected oppositely from the ULIRG with a small amount of rotation. The material which formed the galaxies to the SW has apparently been ejected along this same path but seems to have encountered resistance which has slowed its exit and allowed the development into fairly normal galaxies very close to the ejecting ULIRG. In Fig. 14 the stream of hydrogen drawn out of the parent galaxy and ending exactly on the most active companion (an X-ray and radio source) is evidence for the interaction which braked the normal escape of this material.

Redshifts of ejected compact material are, of course, initially high. We have seen ejected quasars and quasar-like objects in the preceding examples of the active ULIRG's, Mark 273 and Mark 231. Similar candidates are apparent around Arp 220. Much previous evidence has indicated that these intrinsic redshifts decline as the objects evolve into more normal galaxies (Arp 1998a,b). The only question is where they evolve, close to the galaxy due to interaction, or further out if the proto galaxy came out, for example, along the minor axis of an ordered galaxy. Empirically there has been evidence starting in 1970 that companion galaxies have systematically higher redshifts than their parent galaxies and this could only be reasonably accounted for by time dependent, intrinsic redshifts associated with their more recent creation.

We will see another example, almost identical to the companions just discussed for Arp 220, when we later consider briefly the active radio source 3C31/NGC383.

11. Secondary ejection from the $z = .09$ galaxies

In order to measure the redshifts of the galaxies immediately SW of Arp 220 Ohya et al. (1999) placed a one arcsec wide slit at an angle that passed through the three largest companions. As Fig. 16 shows, this slit serendipitously intercepted 4 much fainter galaxies on a line SE of the brightest companion. The redshifts of three of these objects could be measured from their emission lines. They turned out to be $z = .528$, $.529$ and $.523$.

Pursuant to conventional practice the investigators concluded that all of these objects were accidental projections of objects at different distances. The picture was that of galaxies of $z = .09$ at 5x greater distance than Arp 220, with the higher z objects at a further 6x greater distance, all accidentally aligned closely in the same line of sight. However, if one computes the density of just the three faint objects in the 1×16.5 arcsec area of the sky in which they were found, one comes up with the astonishing

figure of more than 2 million per sq. deg. Out to a radius of 37 arcsec from the galaxy B/C there should be over 800 such objects unless they are preferentially distributed along just the alignment of the spectrograph slit back to the large galaxy. It is instead attractive to consider that these $z = .5$ objects were ejected from the active X-ray and radio galaxy at $z = .09$. They themselves are emission line objects which makes the chance of their being accidental background galaxies less (Arp 1982,p.62).

The brighter galaxies at $z = .09$, in turn, are much too close to Arp 220 to be accidental. (At their apparent brightness of $m_R = \leq 15.5$ mag. about .03 galaxies would be expected this close to Arp 220 and, of course, very few would be X-ray sources). *Moreover these otherwise morphologically normal galaxies would be of supposed quasar luminosities if placed at their redshift distances* (Ohya et al. 1999 Table 2). Overall, considering the HI and X-ray connections, it would be difficult to avoid interpreting these $z = .09$ galaxies as having been ejected from Arp 220 and then having ejected even higher redshift objects. Empirically it seems to be another case of associated companion galaxies of various higher redshifts (Arp 1998a).

12. The larger neighborhood of Arp 220

Fig. 17 shows a larger field around Arp 220 in X-rays. It is clear that the outermost X-ray sources, Nos. 1 and 10, continue the "S" shape from the more interior regions pictured in Fig. 15. It is important to note that sources Nos. 2 and 9 (RSO and BSO in Fig. 15) are exactly aligned and almost exactly spaced across the central ULIRG. The outer pair, Nos. 1 and 10 in Fig. 17, are also exactly aligned and almost exactly spaced.

The inner and outer pairs of X-ray sources therefore support the picture of ejection with a slight counterclockwise rotation. The fainter sources interior to the BSO source in Fig. 15 lead directly in along this spiral path, through the companions at $z = .09$, and then into the ULIRG. The overall picture is then one of material ejected from the active galaxy some of which develops into smaller objects of variously higher redshift. We next look at the outermost regions surrounding Arp 220 in an attempt to define over how large an area on the sky the association extends. To do this we process the full field of the archived PSPC observations as was done earlier for Mark 273 and Mark 231. The results are shown in Fig. 18.

The most striking aspect of Fig. 18 is that the X-ray sources, particularly the faint ones, are distributed in long extensions to the NW and SE. The inner "S" shape has turned over into an alignment across Arp 220 with a relatively small rotation of the inner sources, the same as observed in Figs. 15 and 17. One can see the slightly smoothed background in Fig. 17 extending away on either side in this large distribution of X-ray radiation.

Of considerable interest is the radio source 3C321. It is optically identified as a S2 galaxy of $V = 16.0$ mag. Al-

though one of the more intense radio galaxies in the sky it was not detected in X-rays by the Einstein IPC (Fabbiano et al. 1984). In the ROSAT PSPC observation reduced here it is clearly identifiable but too near the edge of the field (56 arcmin) to obtain a reliable flux measure. Note that 3C321 at $z = .096$ could represent material ejected unimpeded at the same epoch as the $z = .090$ galaxies which were stopped close to the SW edge of Arp 220.

As to the radio map of 3C321, two strong lobes are well aligned back toward Arp 220. Since there is no ready explanation for such an alignment one would ordinarily assume it was accidental. We have seen, however, near alignments in double radio sources near Mark 273, Mark 231 and along the X-ray ejection axis from NGC2639 and NGC5985. (The latter two are not discussed here).

That 3C321 is physically associated with the apparent ejection alignment from Arp 220 is supported by the map in Fig. 19. There all the bright radio sources and all the bright infrared point sources have been plotted for a degree around Arp 220. The line through the ULIRG comprises 6 out of the 8 radio sources in the area and 5 out of the 7 IRAS sources. Moreover that line coincides closely with the line of X-ray sources, as can be seen by referring to Fig. 18 directly above it.

13. Bright X-ray sources in the Arp 220 field

It is very important to note the optical identifications of the X-ray sources which make up this extended spiral alignment in the Arp220 field. Table 3 shows that the strong source 20.3N is identified with a blue compact galaxy of relatively bright apparent magnitude. The other strong source, 20.3S is identified with a blue stellar object which is also unusually bright in apparent magnitude. These two strong sources form a conspicuous pair across the active central galaxy.

TABLE 3

Bright X-ray sources in the Arp 220 field							
Cts	R.A.	(2000)	Dec.	E	O-E	ID	Remarks
20.3N	15 33 54.7	23 56 15	16.34	.93	c.g.	BSO's	near
5.0	15 34 07.7	23 29 39	18.28	1.19	BSO		
8.9	15 34 51.0	23 46 05	20.65	.73	BSO	possibly	
"	15 34 51.8	23 46 03	21.59	<1.59	BSO	dbl QSO	
9.6	15 34 55.0	23 28 43	-	-	gal	SW plume	
7.3	15 34 57.3	23 20 12	13.88*	.88*	Sey	Arp 220	
2.8	15 35 02.3	23 15 29	15.93	2.98	RSO		
6.9	15 35 06.1	23 36 56	19.61	2.18	RSO		
4.2	15 32 08.2	23 28 21	17.27	.99	BSO		
9.4	15 37 09.6	23 28 36	19.88	1.22	BSO:		
20.3S	15 37 14.5	23 00 40	17.74	.76	BSO		

* V and B-V

As experience has shown, the outer members of ejected pairs tend to be brighter, lower redshift, transitions between quasars and galaxies. (See particularly Chu et al. 1998; Arp 1998b; 1999). It would therefore be predicted that 20.3N would spectroscopically turn out to be an ac-

tive, moderately high redshift, compact galaxy and 20.3S a moderately low red shift quasar. The inner quasar candidates would be predicted to turn out to be fainter, higher redshift quasars.

In this respect it is interesting to note that in Table 3 the source at 6.9 cts/ks is identified with a very red optical object. A ROSAT HRI position agrees with the PSPC in identifying a very faint optical candidate. Together with its redness it would suggest that the quasar candidate was highly dust obscured. This in turn would be highly interesting because it would suggest that the famously heavy dust absorption in the central ULIRG extended to at least 8 arcmin angular distance from Arp 220.

Of course there are a number of further quasar candidates identified in Table 3. A line consisting of 9.4, 4.2 and 5.0 cts/ks sources goes roughly E-W. This is consonant with ejection in more than one direction as observed in the cases of Mark 273 and Mark 231 and other cases mentioned earlier. The pairs of quasar candidates identified in Tables 1 through 3 should be studied with the aim of obtaining further empirical data concerning the speed, orientation and evolutionary behavior of the ejected matter.

14. Soft X-ray absorption from Arp 220

When a column of hydrogen (N_H) containing X-ray absorbing metals intervenes, the soft X-rays will be absorbed and the hardness ratio will approach $HR1 = 1$. As Fig. 20 shows, the sources around Arp 220 are conspicuously shifted toward this high hardness ratio. The dashed line represents a control field around a bright star, HR8905, which is at a comparable galactic latitude. The estimated excess in hardness ratio from Fig. 20 is about 0.4 in HR1. This translates into a difference in visual absorption of $A_V = .22$ mag.

In the detailed discussion in Appendix A we will argue that the actual absorption is much greater than this minimum value. This means that in addition to absorption from our own galaxy at this galactic latitude there is extra reddening and absorption from the material in the environs of the ULIRG. *The surprising conclusion is that the absorption extends out at least as far as 20 arc minutes and probably beyond 30 arcmin radius!* Thus the gaseous component of the system extends over a degree in diameter on the sky. This angle is of the order subtended on the sky by larger Local Group Galaxies such as M33!

We have seen individual, bright X-ray sources associated out to a diameter approaching 2 degrees around Arp 220. But they may not be bound. The absorbing gas, however, is much more likely to be travelling at less than the escape velocity and this raises the question of what the system will evolve into - a large low redshift galaxy or a low redshift cluster of galaxies? In either case the empirical evidence on the apparent diameter requires the system to

be much closer than the redshift distance of the central, ejecting galaxy.

The same situation applies to the ULIRG's Mark 273 and Mark 231. Although we do not show the HR1 off - axis plots here, it is readily apparent that they have 5 -9 sources which fall significantly above field sources at the same galactic latitude and extend to radii of 20 arcmin and beyond. Such sources mark these systems as also extending to large angular diameters on the sky and thus closer than their redshift distances.

15. Spectroscopic observations in Progress around Arp 220

A joint observing project on optically identified X-ray sources around active galaxies is currently being carried out by E.M. Burbidge, Y. Chu and H. Arp. Measures by Chu with the 2.2 meter Beijing telescope and E.M. Burbidge with the 3 meter Lick Observatory reflector have yielded results some of which are in the process of being reduced and reported.

In the case of Arp 220 it can be said that the two brightest X-ray sources in the field are 20.3 cts/ks (20.3N and 20.3S in Table 3). The physical association of this pair of X-ray sources is suggested by the fact that they are so much brighter in X-rays than the remaining sources in the field and that they are almost exactly equal in X-ray flux. These two have now been confirmed as quasars, they are of low and rather similar redshift which would support the inference from their diametric positions that they had been ejected in opposite directions from the active nucleus.

An even more exciting result is in the process of final reduction. This is the pair of X-ray sources labeled RSO and BSO in Fig. 15. These two sources are aligned as exactly as can be measured across the nucleus of Arp 220 and are evenly spaced, each at about 7.3 arcmin distance. It is also apparent from Fig. 15 that there is a line of 4 or 5 X-ray sources which curves through the $z = .09$ X-ray galaxies and lead directly to the southern member of the pair of sources, designated BSO.

The candidate labeled RSO (red stellar object) is exceptionally red for a quasar ($O - E = 2.18$ mag.) which makes it about 21.8 mag in the blue - very difficult for a 3 meter telescope located on Mt. Hamilton above the lights of San Jose. Nevertheless a 50 minute spectroscopic exposure recorded strong emission lines which unmistakably signaled a quasar! Immediately thereafter the southern member of the pair (BSO) was observed and it turned out to have less strong lines but at very closely the same wavelength as the RSO. As a result we have a pair of quasars extremely well aligned across Arp 220 with closely the same redshift.

Added to the pairing properties, of course, is the line of X-ray sources connecting BSO back to Arp 220. The unusual redness of the northern member of the pair may be related to the huge amounts of dust and absorption

in the ULIRG. If entrained material is drawn out in the process of ejection, the quasar could be involved in a dense cloud of dust. The southern member is not so red ($O - E = 1.07$) but this is still somewhat red for the usual quasar. X-ray material, however, seems to have been shed behind it in its outward track so more of the obscuring material may have been shed than for the RSO ejected in the other direction.

16. Note in appendix which deals with absorption over the field associated with ULIRG's and disturbed galaxies

Please see Appendix A for detailed discussion of the X-ray hardness ratios as a measure of absorption and also some consequences of depressing the counts of more distant, background sources.

17. Note added on quasar near Mrk 273

E.M. Burbidge has kindly allowed her spectroscopically determined redshift of $z = 1.168$ for the 18.1 mag. BSO SE of Mrk 273 to be quoted. This is a particularly important redshift because of its similar magnitude, strong X-ray flux and close proximity to the previously known $z = .941$ quasar. When corrected to the reference frame of Mrk 273 ($z = .038$) the new redshift goes to $z = 1.089$ and the .941 redshift goes to $z = .870$. This means the redshifts fall very close to the quantized redshift peak at $z = .96$ for quasars in general (Arp et al. 1990). In fact one redshift differs by only $+.066$ and the other by $-.055$ from the $z = .96$ peak. These are characteristic peculiar velocities relative to the parent galaxy (Narlikar and Arp in preparation).

18. Field of NGC6204

There is only a 5.2 ks PSPC exposure available for this fourth, bright ULIRG. Consequently only the brightest X-ray sources can be examined (above 3.7 cts/ks). Fig. 22 shows that these X-ray sources are distributed principally along directions NE and SW from NGC6240.

Inspecting the sources within 1 deg. radius around NGC6240 as compiled by SIMBAD it is clear that also radio sources run approximately out to the NE along this same line. In Fig. 21 we show in a gray scale map the disposition of radio sources as recorded in the VLA continuum survey (nvss). Proceeding outward from NGC6240 there is an extended radio source 5.4 arcmin to the east of the ULIRG. It is low surface brightness and not readily identifiable with any optical object. Probably it represents some radio plasma ejected in this direction. Further out along a line to the NE is a string of four radio sources. Somewhat above this line are four X-ray sources. The arrangement and spacing of the outer three sources is similar - and reminiscent of the correlation between radio and X-ray sources which we saw around Mark 231 (Fig. 9).

Going in the other direction, we see three strong radio sources in a line to the W. The striking feature here is that two of the sources are very close doubles. We have seen a strong tendency in all of the previously mentioned active objects for the associated sources to be double. At such small separations they stand out from the rest of the radio sources in the field of Fig. 21 and are therefore additionally indicated to be physically associated with NGC6240. The doubleness might be attributed to their (recent) origin in a typical opposite ejection from an ejected denser body which may or may not be in the near vicinity.

The radio sources pictured in Fig. 21 are mostly confirmed in the 4850 MHz surveys (Griffith et al. 1995) and the 365 MHz survey (Douglas et al. 1996). But those fields extend further to the S than pictured in Fig. 21 and show a strong radio source to the SW which strengthens the appearance of a straight NE - SW line through NGC6240 (as in the map only of X-rays shown in Fig. 22). The only three galaxies shown by SIMBAD in this field also fall approximately along this line. The central of these three falls about 12 arcmin NE of NGC6240, is 15.7 mag. and an IRAS source. Optical identifications should be made for these X-ray and radio sources and spectroscopic measures made also on the galaxies in order to study the details of their association.

19. The bright radio galaxy 3C31/NGC383

Although NGC383 is not classified as an ULIRG (it only has a flux of 1.2 Jy at 100 microns), it is 1.5 mags brighter in the blue than Arp 220 and exhibits some of the same characteristics as the galaxies we have just been investigating. In particular it is a strong X-ray source and has strong, ejected radio filaments which lead toward companion galaxies which are also X-ray sources. Curiously, it has an almost identical redshift to Arp 220, $z = .017$ for NGC383 compared to $z = .018$ for the extreme ULIRG. NGC383 is, however, the 13th strongest radio E galaxy in the sky at 1420 MHz, and among that group, the 9th brightest apparent magnitude E galaxy (Arp 1968a). It has an emission lines which are ionized from the nucleus and probably shows a weak, broad emission component (Owen, O'Dea and Keel 1990).

The most important feature for our purposes, however, is shown in Figs. 23 and 24 where it is seen that there is a tight group of galaxies which are strong in X-rays (1E 0104) and exhibit an X-ray tail pointing back toward NGC383. The resemblance to Arp 220, as it was pictured in Figs. 13 -15, is remarkable. The startling fact then emerges that the redshift of the group associated with Arp 220 is $z = .09$, very similar to the redshift of the group associated with NGC383 which is $z = .11$.

There is strong additional evidence for ejection of X-ray objects in Fig. 23. Most of the discrete X-ray sources surrounding NGC 383 lie on opposite ends of diameters passing close to the central galaxy. Most prominent is a

line of sources at p.a. = 23 deg., including the 1E 0104 X-ray galaxy group. Both outer sources are elongated along this diameter. Fig. 23 also shows a pair of strong sources at p.a. = 100 deg. with material connecting back to the central X-ray mass. A weaker pair is seen at p.a. = -45 deg. with the NW component a double elongated back to the center. The innermost pair is particularly well aligned at p.a. = 60 deg. with the SW component exhibiting isophotes which conspicuously connect back to the central galaxy and the NE component being a close double source.

The most significant aspect of these observations must be the X-ray filaments and isophotal extensions which lead back to the central source. Just examining the X-ray map of the NGC383 surroundings, where the extensions fill a region out to 33 arc min radius, would seem to offer the most direct demonstration possible of the ejection origin of these sources. (The same kind of evidence is available from the galaxy cluster Abell 754 - see Arp 1998a, Fig. 7-17 and also Mark205 on the cover and Fig 1-7). The individual X-ray sources around NGC383 of course should be optically identified as in Tables 1- 3 around the ULIRG's. Presumably they would be mostly quasars whose properties could be usefully compared to those around the ULIRG's.

20. The connection between radio and X-rays

The radio map superposed on the X-ray map in Fig. 25 gives perhaps the clearest evidence for the physical relation between the radio material which is accepted as being ejected, and X-ray material for which similar evidence has been accumulating. We notice that the radio filaments lead in the *general direction* of the X-ray sources, but they deviate somewhat, principally toward the end of the track. This is essentially the same result as gleaned from all the preceding ULIRG's discussed in this paper. In NGC383 the radio track is more continuous and well marked but it is suggested that it is be due to one of the same two causes, or combination thereof:

- 1) The X-ray sources and radio material are ejected along the same track but the motion of the local medium separates the radio plasma from the denser X-ray emitting bodies.
- 2) Successive ejections are rotated and the radio track is an older remnant of a preceding ejection.

In either case the radio and X-ray material should be superposable by simple rotations and translations. In NGC383 the southern extensions seem to be well fitted with a small rotation. The northern radio extension seems to drift, except for a small spot, considerably westward at its end, perhaps due to some perturbation in the medium or local event. (For a purely translational drift note 3C212 in Fig. 10 of this paper).

A corollary to this mechanism is that if the radio and X-ray material try to penetrate through appreciable material in the ejecting galaxy, the radio plasma will be

stripped without ever getting out. This would be a natural explanation of why X-ray ejections seem to come out in several directions but radio ejections tend more to occupy one main channel.

21. Quasars associated with NGC383

There are some bright radio quasars and quasar like objects catalogued within a degree or two of NGC383 ($z = .603$, 1.71 and a Sey1 with $z = .015$ which has a companion of $Z = .287$). But the one for which it is possible to calculate a very high probability of association is B in Fig. 24. It has $z = 2.027$ and falls *only 10 arcsec from A, the main galaxy in the group which has $z = .11$.*

How probable is this to be an accident? In an objective prism survey Weedman (1985) found quasars with $2 \leq z \leq 2.5$ to have a density of .25/sq. deg. at a magnitude of $m_{4500} = 19$ mag. Quasar B has $R = 18.9$ mag. and therefore would have a chance of approximately 6×10^{-6} of falling accidentally within 10 arcsec of galaxy A. Moreover the analysis of Komossa and Boringher (1999) make it seem likely that galaxy A and its group are the source of the strong X-rays. The association of an active X-ray galaxy with the quasar by chance is then vastly less likely. It seems difficult to escape the conclusion that we have another example of a physical association of a high redshift quasar with a low redshift galaxy (Burbidge 1996; Arp 1998a;1999). It is to be noted that, although the quasar is within the optical boundaries of galaxy A it shows no absorption lines at $z = .11$ (Hewitt and Burbidge 1993). It shows a series of absorption systems from $z = 1.97$ down to $z = 1.75$ but the absence of absorption lines from A would conventionally argue that it was not behind A.

Of course we have argued that the origin of the group A galaxies was by ejection from the central NGC383. This could make the quasar a secondary ejection from an active, evolving companion or a later epoch proto galaxy either entrained or traveling the same track. What then is the probability that A has come from NGC 383, or for that matter that the quasar has come directly from NGC383?

Fig. 26 shows the X-ray contours obtained from the Einstein IPC. These observations are with a less sensitive detector than used for the ROSAT maps in Figs. 23 and 25 but at a somewhat higher energy, namely the .3 to 3.5 keV band. It is clear that the isophotes of 3C31 are extended toward 1E 0104 and the contours of the X-ray source are extended back toward 3C31. Allowing a generous ± 10 degrees in pointing coincidence, the chances of accidental mutual alignment are about 1 in 100. But now we have to ask what are the chances a 3C radio source would be encountered in an area of 16.4 arcmin radius. About 400 3C sources in about 30,000 sq deg. of sky gives another factor of about 1 in 100. So the total chance of finding a galaxy as active as NGC383 with mutual X-ray alignments to 1E 0104 is about 1 in 10,000.

But perhaps the most compelling evidence for association is the similarity with Arp 220, where a tight group of X-ray galaxies of about the same redshift are linked directly back to the ULIRG by X-ray and HI material.

22. Distances and quantizations of redshifts

The angular distance from Arp 220 to its associated ($z = .09$) galaxy group is 2 arcmin whereas it is 16 arcmin in the ($z = .11$) NGC383 case. The brightness of the NGC383 system makes it tempting to account for this by arguing that NGC383 is nearer the observer. But we should remember that the 3C321 sytem at $z = .096$ was also associated with Arp 220 but at 56 arcmin radial distance. We argued there that the retarding interaction with the ejecting galaxy might determine the different distances traveled by the ejecta at their observed evolutionary stage.

The distances of these parent galaxies is difficult to estimate because their redshifts appear to be an intrinsic property related to their age rather than a measure of their distance. There are several ways of seeing this. One is through the evident quantization of their redshifts. For example the redshifts of Mark 273 and Mark 231 are $z = .038$ and $z = .041$ respectively. The redshifts of Arp 220 and NGC383 are $z = .018$ and $z = .017$ respectively. The latter redshifts are very close to the 5000 km/sec peak in redshifts over the whole sky but particularly of the Perseus - Pisces filament that stretches almost 90 deg. across the sky. (see Arp 1987 p. 129ff; Arp 1998a p. 149ff). There is an obvious problem with interpreting this as a shell of galaxies expanding away from our own in every direction. As an alternative the above references indicate that, empirically, galaxies at these redshifts give evidence of being associated with brighter, more nearby galaxies. In the case of 3C31/NGC383 it falls only 3.2 deg. away from the Local Group Seyfert 3, NGC404.

It is also evident that quasars in these systems which have measured redshifts come close to the global redshift peaks of $z = .06$, $.30$, $.60$, $.96$, 1.41 , 1.96 , 2.64 ...etc. For example the quasar B, SSW of NGC383 has $z = 2.027$. (In the reference frame of NGC383 $z_Q = 1.976$). The intrinsic redshifts seem to decline in discrete steps as they evolve toward more normal galaxies. It would be natural to reason that the ULIRG's and other active galaxies are part of this evolutionary sequence and still have a dominant component of the age related redshift which is quantized. For this reason it might be better to estimate the distance from the apparent magnitude of the quasars. In the systems we have been examining, the quasars are quite bright in apparent magnitude. The quasar B again, for example, is $R = 18.9$ mag. This is bright for a quasar of this redshift and is similar to the properties of the line of quasars coming SW from M33, another Local Group galaxy near NGC404 and NGC383. (See Arp 1987 p.71ff).

An other example of an object like those we have been studying is shown in Fig. 27. It is the disturbed

spiral IC1767. Amazingly it has a redshift of $z = .0175$, just between that the .018 of Arp 220 and the .017 of NGC383. It has been argued to be a southern extension of the Perseus-Pisces Cluster (Maurogordato, Proust and Balkowski 1991). Like NGC383 it is only a modest infrared, IRAS source of flux 1.0 Jy at 100 microns (but rising steeply toward longer wavelengths).

Like Arp 220 and NGC383, IC1767 shows evidence for ejecting radio sources and higher redshift objects. Its most outstanding feature is a pair of very strong radio sources aligned across it at 1.3 deg separation on the sky. This pair was so strong it was identified 31 years ago (Arp 1968b). Subsequently the radio sources were measured to be quasars, both very close to $z = .6$. (If one refers the redshifts to the central galaxy they become $z = .588$ and $.640$, which, after allowing for about $cz = .02$ toward and away ejection velocity, gives *both* quasars very close to the major quantization peak of $z = .60$. The combination of these properties with the strength of the radio sources and closeness of alignment gives negligible chance of accidental association of these quasars.

The argument now centers on the properties of these $z \sim .6$ quasars. they are unusually bright in apparent magnitude, $V = 17.09$ and 16.40 mag., exceptionally bright in radio wavelengths, and unusually widely spread across the central galaxy. All these properties argue for an unusually closeby system. Thus it becomes another argument for the active objects like Arp 220, NGC383 and IC1767 to belong to the Perseus-Pisces redshift peak, but for all these galaxies to be much closer than their conventional redshift distance.

23. Summary: Empirical Properties of Active Galaxies

The operational definition of an "Ultra Luminous" galaxy is one which deviates strongly above the Hubble relation between redshift and apparent magnitude. Since the class of galaxies we are investigating here differs in spectroscopic and morphological characteristics from the one that defines the Hubble relation, the latter cannot be used to define the distances or luminosities of the ULIRG's. In fact the class of active and high surface brightness galaxies - Seyferts, compacts and quasars - defines a conspicuously steeper slope than the Hubble slope (Arp 1968a; 1998a, Fig. 2 - 19), ruling out expansion velocity redshifts unless the luminosities are progressively adjusted to compensate.

We have investigated here a sample of active galaxies with the most extreme deviation from the Hubble relation. We have found them to be strong X-ray sources, show vigorous ejection of radio material and generally disturbed morphologies. They do not look like the relaxed, symmetric galaxy forms of the most luminous nearby galaxies - whose distances do not depend on redshift. Characteristically the central active galaxy has physically associated companions which are even more active and of various de-

grees of higher redshift. The activity and morphological disturbances seem to be associated with lower rather than higher luminosity and there are many new cases presented here of apparently younger companions with higher redshifts than their galaxy of origin.

Mark 273 at $z = .038$ shows X-ray and optical connections to an active companion object at $z = .458$. Optical and radio connections lead toward a pair of optical and X-ray bright quasars one of which has $z = .941$. Many strong X-ray pairs across Mark 273 have been optically identified as almost certain quasar candidates. A line of 100 micron infrared sources extends over 20 arcmin from Mark 273. Their nature and relationship to Mark 273 is a mystery to be investigated.

Mark 231 at $z = .041$ shows well marked radio ejections in two, roughly orthogonal directions. X-ray sources are associated with these radio patches in such a way as to suggest the radio plasma is in varying degrees of being stripped from them. *The close double nature of many ejected radio sources is again seen and becomes a general characteristic of ejecta from these active systems.* A string of infrared sources stretches over 3 degrees from Mark 231 in the direction of a major interior radio ejection from this active ULIRG! Eleven quasar candidates are optically identified as BSO or Bcg candidates, many in pairs.

Arp 220 at $z = .018$ has a group of X-ray galaxies at $z = .09$ linked to it by neutral hydrogen extensions. Moreover they are a part of a chain of X-ray sources emanating from the central ULIRG in a shallow spiral shape which has knots paired closely across the central object. The interpretation would seem to require ejection with rotation. *The 50 x 50 arcmin field shows the inner "S" shape bending over into an extended spiral distribution of X-ray sources of the order of 2 degrees in diameter!* Radio and X-ray sources are shown to extend along this same line and for the same distance. Heavy absorption over the Arp 220 area shows up in the hardening of the X-ray sources over an area of the order of a degree in diameter.

NGC6240 at $z = .024$ shows in a short exposure, X-ray sources extending on a line either side of the the ULIRG. Radio surveys show lines of radio sources extending out farther than 40 arcmin. Double sources are again featured.

The bright radio galaxy NGC383 at $z = .017$ shows pairs of X-ray sources connected diametrically across it. The strongest pair includes a group of X-ray galaxies at $z = .11$. There is a quasar of redshift $z = 2.027$ only 10 arcsec from the central galaxy in this group and they are both apparently associated with the central radio galaxy (3C31). The radio extensions from 3C31 are the strongest of any of the cases and appear to be only slightly displaced from the main X-ray ejections.

Note the similarity of the X-ray galaxies of $z = .11$ associated with NGC383 to the X-ray galaxies of $z = .09$ connected to Arp 220. In one of the best marked ejection lines from a Seyfert galaxy, NGC3516 (Chu et al. 1998), the last X-ray galaxy in the line has $z = .089$. The latter

confirms both the ejection origin of these galaxies and the quantized nature of their redshifts. It is suggested that only the distances from the ejecting central galaxy change in accordance with the amount of their interaction as they exit.

An important final point should be that the preceding paper analyzes a more or less complete sample of the brightest ULIRG's. Fainter examples would be expected to follow somewhat the same patterns. In recent sample of faint ULIRG's (Stanford et al. 2000) there is a marked tendency for the central objects, pictured in the K band, to have diametric companions or two or three condensations emerging in a jet like configuration.

24. What are the distances of these active central galaxies?

If we cannot use the conventional redshift distances, then what are the real luminosities of the systems we have been investigating in this paper? I see two possibilities of estimating non-redshift distances:

1) The systems all seem to be ejecting high redshift quasars of the kind that have been physically associated with nearby galaxies. If we view the quasar redshift as signaling an age related phase in its evolution toward a normal galaxy then it may be that at this phase all have similar luminosities (for example if ejected masses are similar). Then we could judge by the apparent magnitude of the associated quasars what the distance was. A preliminary assessment seems to indicate the quasars around the active galaxies investigated here are somewhat brighter than those associated with the sample of Seyferts in Arp 1997. Those Seyferts were judged primarily to be in the Local Supercluster so the active galaxies investigated here would be indicated to be somewhat closer.

2) The angular size of the associations of material we have seen around the ULIRG's in this paper are of the order of a degree radius or more. This would class them with Local Group galaxies. One might argue that the outer sources are escaping into the general field from the central galaxy and only within a much smaller radius does the material fall back in and then evolve into a smaller, more relaxed galaxy or group of galaxies. (This may finally offer a legitimate use for merger calculations).

The intriguing question then arises: Will Mark 273 and Mark 231 evolve into systems like Arp 220 and NGC383 and what will the latter two systems evolve into? NGC383 is firmly a member of the Perseus-Pisces chain. As such it consists of redshifts between 4000 and 6000 km/sec and exhibits extensions of several degrees on the sky. If the redshifts continue to lower and the luminosities increase as all these objects age they may develop into what we consider more "local" groups and clouds of galaxies.

There are two kinds of observations which could shed light on this question:

1) There was an infrared, NICMOS observation (Scoville et al. 1998) of the central regions of Arp 220 which discovered 8 possible star clusters (unresolved). The authors calculated that at the redshift distance of Arp 220 these clusters would have an absolute K magnitude of $M_K = -13.5$ mag. This turned out to be brighter by 1.5 magnitudes than, for example, any in NGC5128, the giant E galaxy also known as Centaurus A. Now if we were to move Arp 220 a factor of 10 closer, that would lower the luminosity of these objects to $M_K = -8.5$, about that of the brightest stars in a galaxy. Have stars been resolved in Arp 220? A factor of 10 closer than its redshift distance would place the ULIRG about half way between our Local Group and our Local Supercluster.

2) Quasar redshifts, as mentioned earlier, are "quantized". Empirically the spread around the preferred values is less for quasars associated with low redshift galaxies (Arp et al. 1990). This has been interpreted as meaning that the $\pm .1c$ ejection velocities carry some quasars out into the field, but those that are captured by the ejecting galaxy must slow down, lose this $.1c$ ejection velocity and assume more closely their intrinsic, sharply quantized redshift values. When such data is available for the systems discussed here it may be possible to identify the gravitational diameter of the system and hence judge its distance by this angular size criterion

In general it could be remarked that there is a quite well established, empirical sequence of evolution from high redshift, compact, low luminosity quasars to brighter medium redshift quasars to compact, active and disturbed galaxies and finally to more relaxed, normal galaxies (Arp 1998b). The intrinsic redshift drops in steps along this sequence and it is implied that the ULIRG's considered here are in a phase of still evolving toward lower redshift - they are evolving from quasars, and like quasars, they are much closer, and less luminous than their conventional redshift distances. If this is true, one piece of terminology which might be salvaged from previous work is the name ULIRG - except that it now would have to mean "Under Luminous" galaxy.

25. Acknowledgements

I would like to thank the many observers who allowed use of their results, some of them unpublished, which enabled a comprehensive view of the properties of these bright, very active galaxies.

26. Appendix A

The ratio of hard to soft X-rays is $HR1 = (A - B)/(A + B)$, where A is the flux between .4 to 2.4. keV and B is between .07 and .4 keV. Testing the behavior of the hardness ratio on a five assumed homogeneous star fields showed that the hardness ratio varies with off-axis distance, crowding

in the center of the field and source strength. The control field HR8905 was chosen as:

1) the closest match to Arp 220 in all these characteristics. ($N_H = .43$ for Arp 220 and $.50 \times 10^{21} \text{ cm}^{-2}$ for the star field).

- 2) Only sources greater than 1.3 cts/ks were used and
3) appreciably extended sources were excluded.

Correcting for a difference of .07 in HR1 due to the different N_H in the two fields gives an estimated excess in hardness ratio from Fig. 20 of about 0.4 in HR1. This translates into a difference in $N_H = .4 \times 10^{21}$ in the hydrogen column and, using the relation $A_V = .56 N_H (10^{21} \text{ cm}^{-2})$ developed by Predehl and Schmitt (1995), a difference in visual absorption of $A_V = .22$ mag. is obtained. Doubling this for the absorption through the entire cluster gives $E_{B-V} = .15$ and $A_B = .6$ mag.

This must be a minimum absorption for the material associated with Arp 220. Some reasons are:

1) When the hardness ratio approaches 1 it becomes an insensitive measure of the absorption (see Pietsch, Trinchieri and Vogler 1998, Fig. 1).

2) If there are any foreground sources in Fig. 20 they would lower the excess hardening attributed to Arp 220.

3) Some objects associated with the ULIRG may be obscured by dense clouds and be below the detection level of the exposure.

In general, however, the points in Fig. 20 spread around the mean by roughly $\pm .4$ as if we were seeing some on the near side and some on the far side of the group.

An absorption value from completely different type of measurement, the Balmer decrement of the emission line galaxy B in Fig. 13 gives $A_V = .51 \pm .1$ mag. (Ohyama et al. 1999). Galaxy B, attached to Arp 220 by X-ray material is surely near the center of the group which implies the absorption A_B through the whole group of 1.4 mag. Since Arp 220 with its enormous absorption and reddening (Becklin and Wynn Williams 1987 estimate 50 magnitudes of visual absorption at the center) lies also in Fig. 20 very near HR1 = 1.0, it implies that that HR1's near this value signal much larger absorptions than the minimums we have estimated. The important result of Fig. 20 then becomes the fact that these high absorptions extend out past 30 arcmin radius.

It should also be noted that recent measures at 200 microns (Alton et al. 1998) show colder dust extending to larger radii than 100 micron dust in resolved galaxies. If this is true of Arp 220 its diameter would grow even larger and raise the question of what is the role of this dust in the evolution of this system.

One point of general interest is that with a minimum of $A_B = .6$ mag. absorption, the normal background count of X-ray sources must be appreciably depressed. But with the larger absorptions indicated in the further discussion, background sources could be almost completely suppressed and therefore almost all the sources actually belong to

Arp 220. This is a point which has not been considered when analyzing presumably distant quasars which show absorption lines from intervening absorption clouds.

For example, in 32 total fields searched for quasars behind elliptical galaxies and clusters of galaxies Knezek and Bregman (1998) found 13 quasars out to distances of $r \leq 13$ arcmin with X-ray counts ≥ 10 cts/sec. The density of these quasars reached from 5 to 8 per sq. deg. between 8 and 2 arcmin from the center. The expected background density of X-ray quasars using their detection success rate was about 1.4 quasars per sq. deg. This concentration of quasars toward the E galaxies and clusters is illustrated in Fig. 28.

The above result addresses a long standing claim that the observation of lower redshift absorption lines in high redshift quasar spectra proved that the quasars were at their large, emission line redshift distances. Of course the only thing that the observation proved was that some quasars were not in front of the clusters. They could be inside the cluster or, if they did not show absorption lines they could be in front, or behind but seen between clear patches. The only decisive observation would be to see if they were more numerous in the direction of the galaxies than the surrounding background. The Knezek and Bregman observations seem to have inadvertently established that. The point that the Arp 220 observations now make, however, is that because of the absorption of the galaxy or cluster (as evidenced by the absorption lines in the quasar spectra) *the background count of quasar density should be to some extent lower in the direction of the galaxy or cluster*. Thus the result quoted above for an excess number in the direction of the galaxies is actually a lower limit because an undepressed background was used for comparison.

In the direction of clusters of galaxies "...the significant overdensity of background bright quasars ... on a scale of 10 arcmin..." was noted by Wu and Fang (1996). Later these authors reexamined the possibility that the excess could be due to gravitational lensing and concluded "...the quasar galaxy association remains an unsolved puzzle in today's astronomy..." (Zhu, Wu and Fang 1997). It should be emphasized that evidence for absorption in the cluster can only strengthen this conclusion.

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Figure Captions:

Fig. 1 X-ray contours on a POSSII, R image of Markarian 273 and 273x from Xia et al. 1998

Fig. 2 Deep R image from the Univ. of Hawaii 88-inch telescope by John Hibbard. Arrow points to Mrk 273x.

Fig. 3 Smoothed and contoured HRI X-ray image of Mark 273 and Mark273x (72 arcsec NE) by Thomas Boller.

Fig. 4 Deeper, lower resolution PSPC X-ray image smoothed and contoured by Thomas Boller.

Fig. 5 VLA, 20cm continuum map of Mark 273 by Min Su Yun.

Fig. 6 VLA radio continuum map from survey (nvss). Strong X-ray sources are marked with x's, including a quasar of $z = .941$ and a BSO of $E = 18.1$ mag.

Fig. 7 X-ray photons in a 50 arcmin radius PSPC field. Brighter sources from the standard detection algorithm are marked in counts per kilosecond. Mark 273 is at center with 13 cts/ks and Mark 273x has 8. The two strong, candidate X-ray quasars in Fig. 6 are marked 21, referred to in text as 21N for North, and 38. The data on the labeled sources is given in Table 1. Note elongation of source distribution NE to SW through Mark 273 and also pairs of sources SE to NW. The picture is 50 arcmin on a side (1 sky pixel = 1/2 arcsec)

Fig. 8 A plot of all infrared sources of greater than .5 Jy at 100 microns within a one deg. radius of Mark 273.

Fig. 9 (a) High resolution radio map of 10.4×20.7 arcmin field around Mark 231. From 20cm, VLA, FIRST survey. Notice the pairs of double radio sources flanking the central galaxy. (b) At the same scale as above, a PSPC X-ray exposure (sources are dark) overlaid with contours of radio sources from the low resolution VLA survey. (c) Optical map of double X-ray source consists of $z = 1.272$ quasar and $O = 19.9$ mag. BSO at p.a. = 75 deg. (nvss).

Fig.10 Radio contours are here superposed on an HST image of the radio galaxy 3C212 (Stockton 1998) Images marked f and g are optical objects

Fig. 11 At an infrared wavelength of 60 microns, a 6.1×6.1 deg. IRAS survey field is pictured

Fig. 12 X-ray photons within about 50 arcmin from a PSPC exposure. Cts/ks are labeled for brighter sources. Mark 231 has 14.3 cts/ks. Data for sources are given in Table 2

Fig. 13 Optical identification of the four largest galaxies around Arp 220 which has $z = .018$. Ohya et al. 1999

Fig. 14 HI contours at the redshift of Arp 220 ($z = .018$) leading down to a group of galaxies at $z = .09$. By J. Hibbard

Fig. 15 Hard X-ray band, .5 to 2.4 keV, smoothed, showing curved string of sources leading down from Arp 220

Fig. 16 The $z = .09$ companions SW of Arp 220 with 4 small high redshift objects circled. Ohya et al. 1999

Fig. 17 Standard detection X-ray sources in a 43×43 arcmin field. No. 3 is Arp 220. No. 7 is a star

Fig. 18 X-ray photons (broad band .11 to 2.4 keV, slightly smoothed) within about a 50 arcmin radius with brighter sources labeled in cts/ks. Arp 220 is in the center, unlabeled, but with a count of 7.3 cts/ks. The $z = .09$ companion galaxies are an extended source of 9.6 cts/ks merged with Arp 220 to the SW at this scale (also unlabeled). The 8.9 and 6.9 sources are Nos. 1 and 2 respectively in Fig. 17, the 2.8 source is No. 10 in Fig. 17 and the source just above the 2.8 (unlabeled in this Figure) is

No. 9 in Fig.17. The radio source 3C321 and its two lobes are sketched in to scale.

The enlarged view in Fig. 17 illustrates how the sources and background radiation in the central regions turn over from an approximately vertical "S" shape to a spiral distribution elongated in the NW to SE direction in this map

Fig. 19 Plot of all radio sources > 70 mJy at 4.85 Ghz (triangles) and all infrared sources $> .7$ Jy at 100 microns (filled circles) within 1 degree of Arp 220. From surveys by Becker et al 1991; Moshir et al 1989

Fig. 20 Hardness ratio, HR1, of X-ray sources as a function of angular distance from Arp 220. The dashed line indicates averages from a control field at similar galactic latitude

Fig. 21 The dark spots show strong radio sources from the VLA low resolution survey (nvss). Small x's show X-ray sources from Fig. 22. Two of the radio sources on a line W of the ULIRG are just discernible as very close doubles. Dashed outline represents an extended radio source. It is 42.5 arcmin from NGC6240 to the westernmost double

Fig. 22 A PSPC X-ray map around NGC6240 (radius ~ 1 deg.) showing standard detection sources with likelihood greater than 10. From S. Komossa, private communication

Fig. 23 A PSPC X-ray map at .5 to 2.0 keV of 3C31/NGC383. Sources pairing across the center are indicated by their position angles. Adapted fom Komossa and Boehringer 1999

Fig. 24 The galaxy group 16.6 arc min SSW of NGC383 (the + marks the centroid of the the X-ray source 1E 0104). Galaxies A,C,E,F have redshift $z = .11$. B is a quasar with $z = 2.027$. Red image by Gioia et al. 1986. Insert at higher contrast shows the quasar embedded in the image of the dominant galaxy

Fig. 25 The same X-ray map as in Fig. 23 but now with the radio jet contours. Overlay of a .6 GHz radio map from Strom et al. 1983 by Komossa and Böhringer

Fig. 26 The X-ray map of NGC383/3C31 from the Einstein Laboratory IPC. Two stars have been removed from the figure published by Gioia et al 1986

Fig. 27 Very strong radio sources form a pair across the disturbed spiral IC1767. Their redshifts are close to the $z = .60$ quasar peak and the galaxy's redshift is at the 5000 km/sec galaxy peak

Fig. 28 Density of quasars found near E galaxies and the centers of galaxy clusters by Knezek and Bregman (1998). The background is calculated from the density of X-ray sources with their quasar detection rates but with no background count suppression from absorption by the central object